ARS 42-46
April 1961

Some Effects of CONSTRUCTION and CLIMATIC FACTORS on Heating

Five Expansible Farmhouses

Growth Through Agricultural Progress

AGRICULTURAL RESEARCH SERVICE
U. S. DEPARTMENT OF AGRICULTURE

PREFACE

This publication is one of a series to be issued covering studies in five expansible-type houses built at the Agricultural Research Center, Beltsville, Md., in 1952, 1953, and 1954. The houses have been occupied most of the time since they were constructed and thus the research on them includes "in-use" performance characteristics of various kinds of materials, construction, and heating systems. Family reaction to these characteristics and to certain construction features, as well as the climatic responses of the various houses are important aspects of the research conducted in the houses.

The Agricultural Research Service's Clothing and Housing Research Division, Institute of Home Economics, and the Agricultural Engineering Research Division, through its Farm Electrification Research Branch and the Livestock Engineering and Farm Structures Research Branch, cooperated on certain phases of the program.

ACKNOWLEDGMENTS

The contributions of industry in supplying certain materials for the construction of one of these houses are gratefully acknowledged.

The authors gratefully acknowledge the assistance of J. R. Dodge, formerly with this Division who initiated the study, and of A. A. Biggs, of the Livestock Engineering and Farm Structures Research Branch, and of others too numerous to mention. They are particularly grateful to Wallace Ashby, formerly Head of the Livestock Engineering and Farm Structures Research Branch, for his assistance in the conduct of the project and analysis of data.

CONTENTS

SOME EFFECTS OF CONSTRUCTION AND CLIMATIC FACTORS ON HEATING FIVE EXPANSIBLE FARMHOUSES

Harold J. Thompson[1] and Joseph W. Simons
Agricultural Engineers, Livestock Engineering and Farm Structures Research Branch
Agricultural Engineering Research Division, Agricultural Research Service

INTRODUCTION

Cost-saving features and unconventional types of construction for residential use are current topics of widespread interest. Features such as concrete slab floors laid on the ground, exposed rafter roof construction, and large window areas have become popular.

Such features and types of construction may have somewhat different influences on the climatic responses of family dwellings as compared with conventional construction. Little has been done to evaluate the "in-use" performance of these various features and construction types. This is particularly true of farmhouses, where "in-use" performance characteristics may be somewhat different than houses in urban areas. Such variations may be due to differences in exposure to climatic factors such as sun, wind, and temperature.

Family living habits have changed. For example, generally all parts of the house are now used both summer and winter and uniform temperatures throughout the house are demanded by the family. New equipment such as dishwashers and dryers are used by many. All of these factors tend to have some influence on fuel or energy requirements.

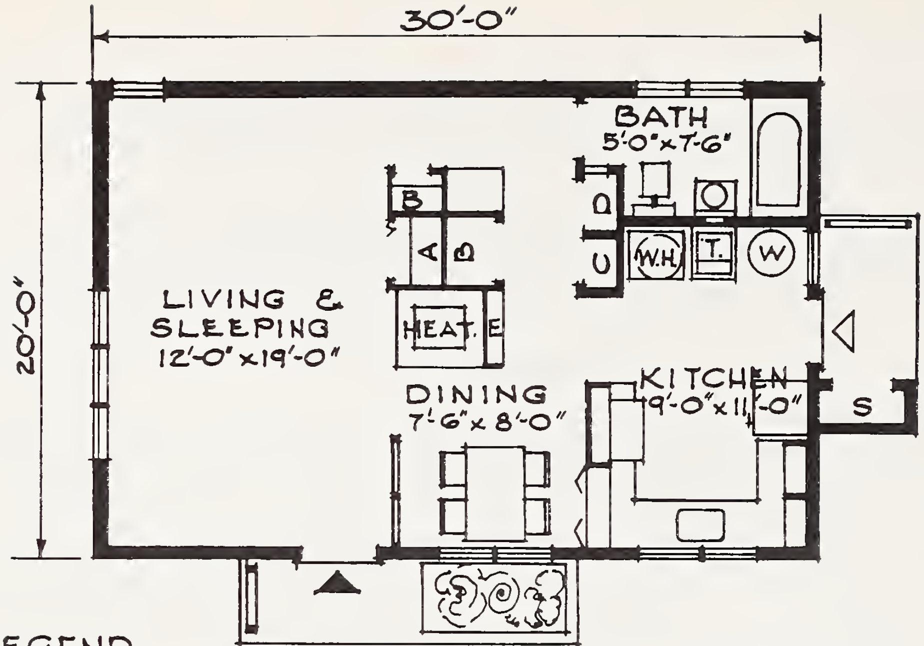
The need for basic changes in the construction of houses to meet these new needs and the evaluation of performance characteristics have become more evident in recent years as people try to remodel existing homes or build new ones.

DESCRIPTION OF STUDY AND FACILITIES

Five expansible-type houses were built on the Dairy Husbandry farm at the Agricultural Research Center, Beltsville, Md., for the primary purpose of housing farm workers. The construction of these houses afforded an opportunity to study experimental designs utilizing a variety of construction methods and materials. Low cost features such as exposed brick for interior surfaces, spaced sheathing underwood siding, and frameless windows were incorporated in the designs for evaluation by the investigators and occupants. Although built primarily for workers, the houses also provided an excellent opportunity for studying the "in-use" performance characteristics, especially the influence of weather and type of construction on fuel required for heating in winter. It was recognized at the beginning that the study could not be highly scientific because of the many uncontrollable factors. Tenants were not asked to change their regular routine of family living nor to follow any set pattern of house operation. Under these conditions it was impossible to obtain the kind and quantity of data which would be desirable for a comprehensive study.

Photographs of the five houses are shown in Figures 1 through 5 and the site plan is illustrated in Figure 6. A general description of the construction and floor and window areas for each house is given in Table 1. Detailed plans and working drawings of Houses A, B, C, D, and E (Plan Nos. 7061, 7062, 7079, 7128, and 7130, respectively) are available through the Agricultural Extension Service in some States.

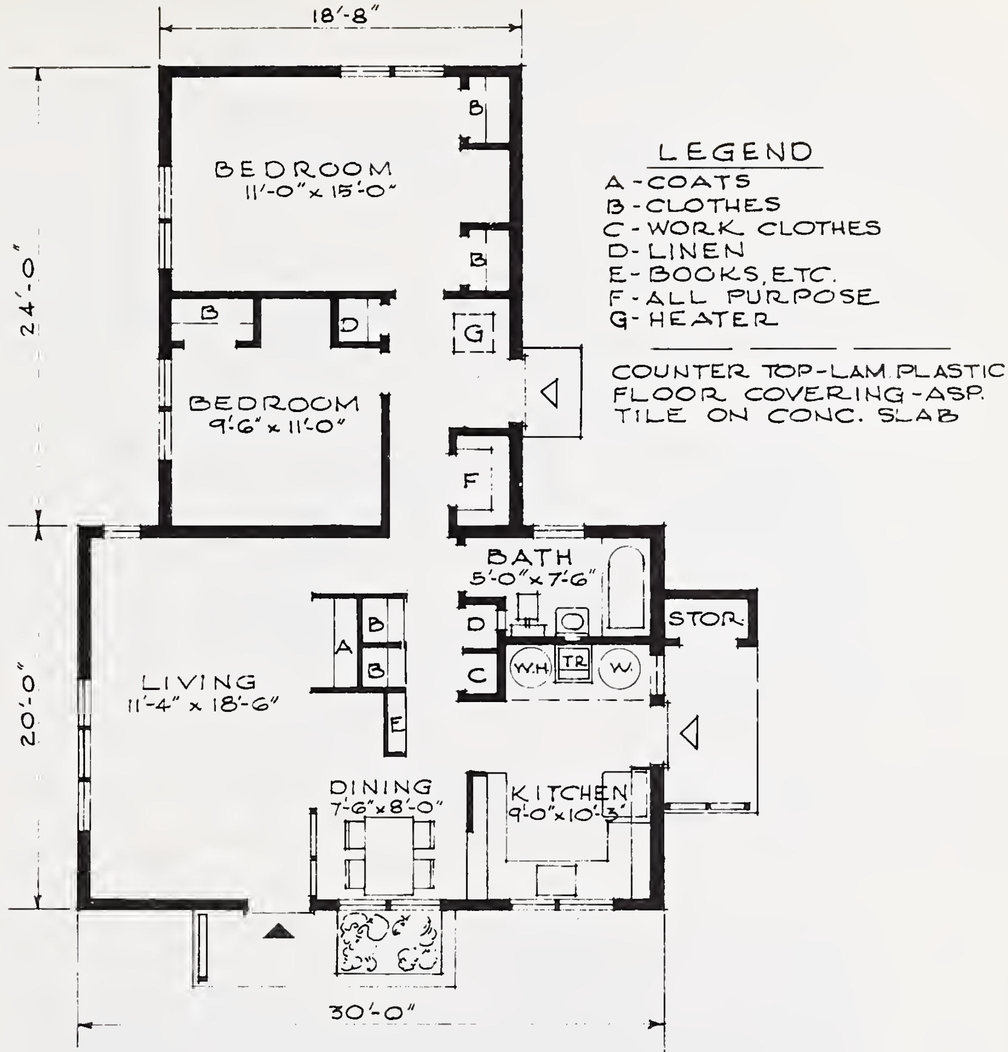
[1] Now employed by Administrative Services Division, ARS.



LEGEND
A-COATS
B-OTHER CLOTHES
C-WORK CLOTHES
& CLEAN. EQUIP.
D-LINEN
E-BOOKS

COUNTER TOP-LAMINATED PLASTIC
FLOOR COVERING ON CONC. SLAB
BATH-VINYL TILE
ALL OTHER-ASPHALT

FIGURE 1.--House A.



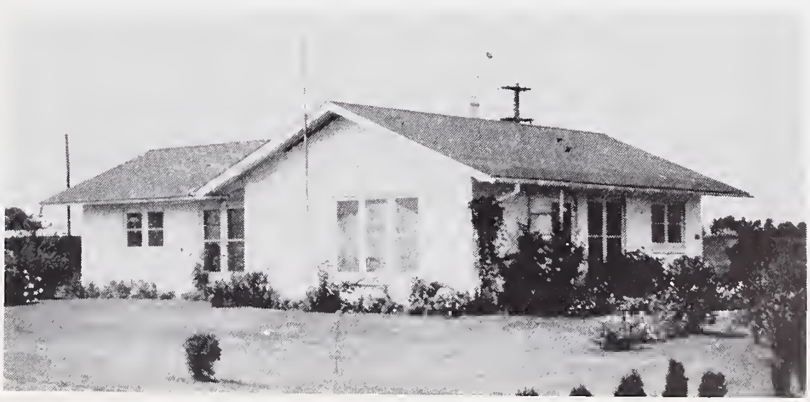


FIGURE 2.--House B.

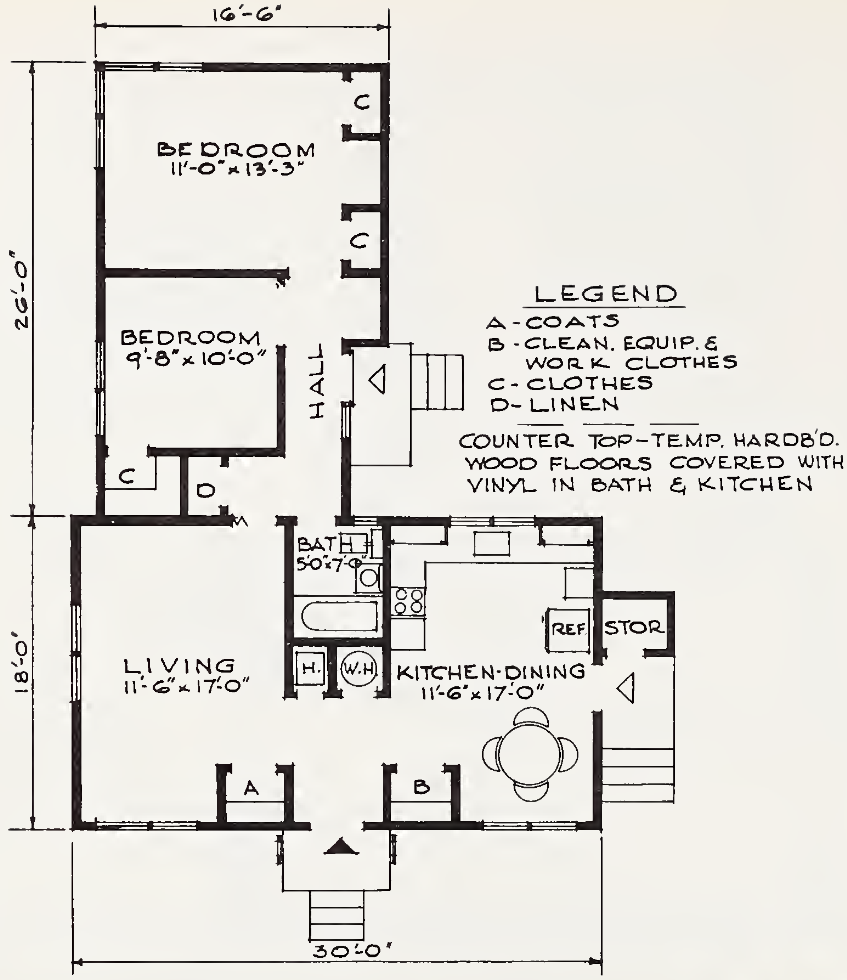
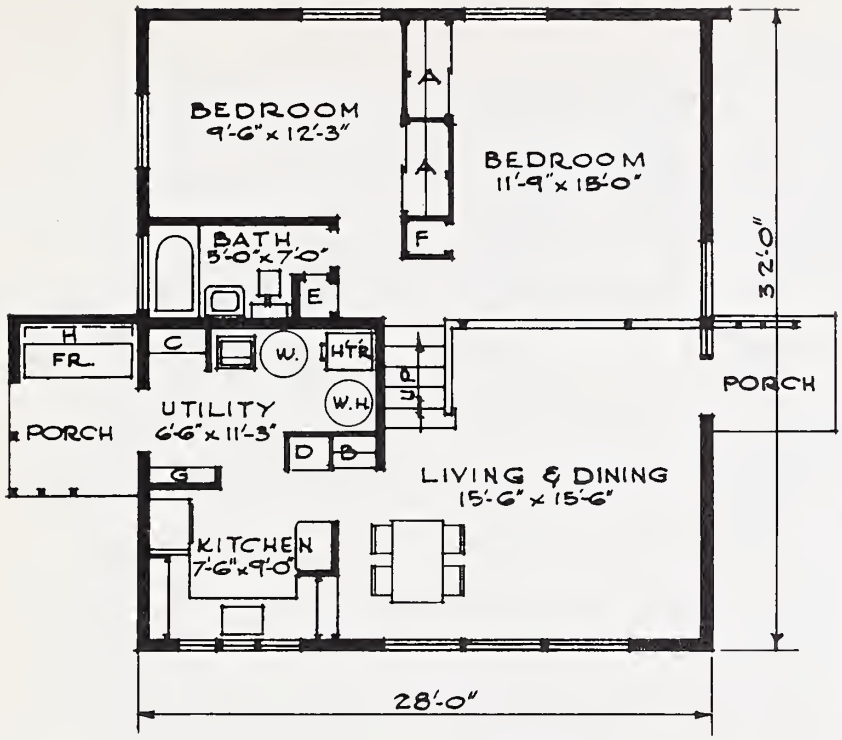


FIGURE 3.--House C.



LEGEND

A-CLOTHES
B-COATS
C-WORK & PLAY CLOTHES
D-CLEAN. EQUIP. & SUPPLIES
E-LINEN
F-MISC. TOYS, ETC.
G-CANNED GOODS
H-UTILITY

COUNTER TOP-LAM. PLASTIC
ASPHALT TILE, LOWER LEVEL
EXPOSED SLAB, UPPER LEVEL

FIGURE 4.--House D.

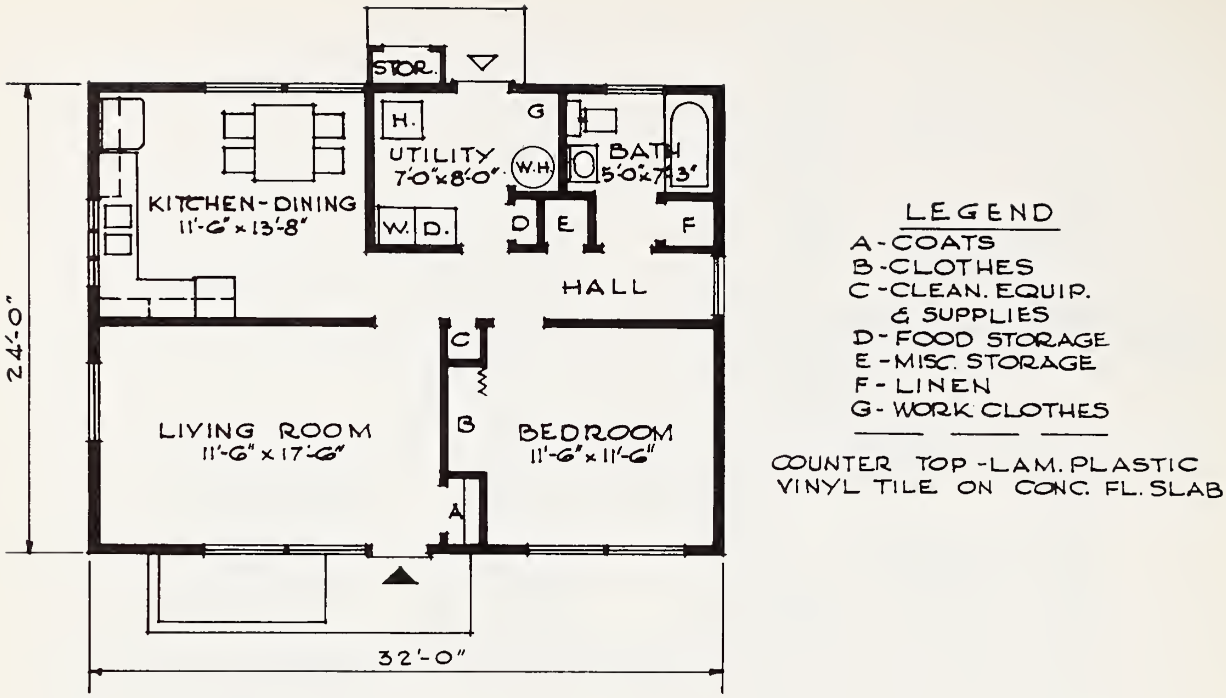


FIGURE 5.--House E.

The basic unit of House A was constructed during the summer of 1952 and occupied that fall. The basic units of Houses B and C were also completed during the summer of 1952 but two bedrooms were added to each house before they were occupied in the fall. The split-level house, D, was completed and occupied early in the spring of 1954. House E was completed during the summer and fall of 1954 but was not occupied until November 1955.

DESCRIPTION OF TESTS AND EQUIPMENT

Fuel consumption and inside-outside air temperature differences were the two chief variables measured for Houses A, B, C, and D, beginning in December 1955. Similar information was obtained for House E except that electricity for the heat pump

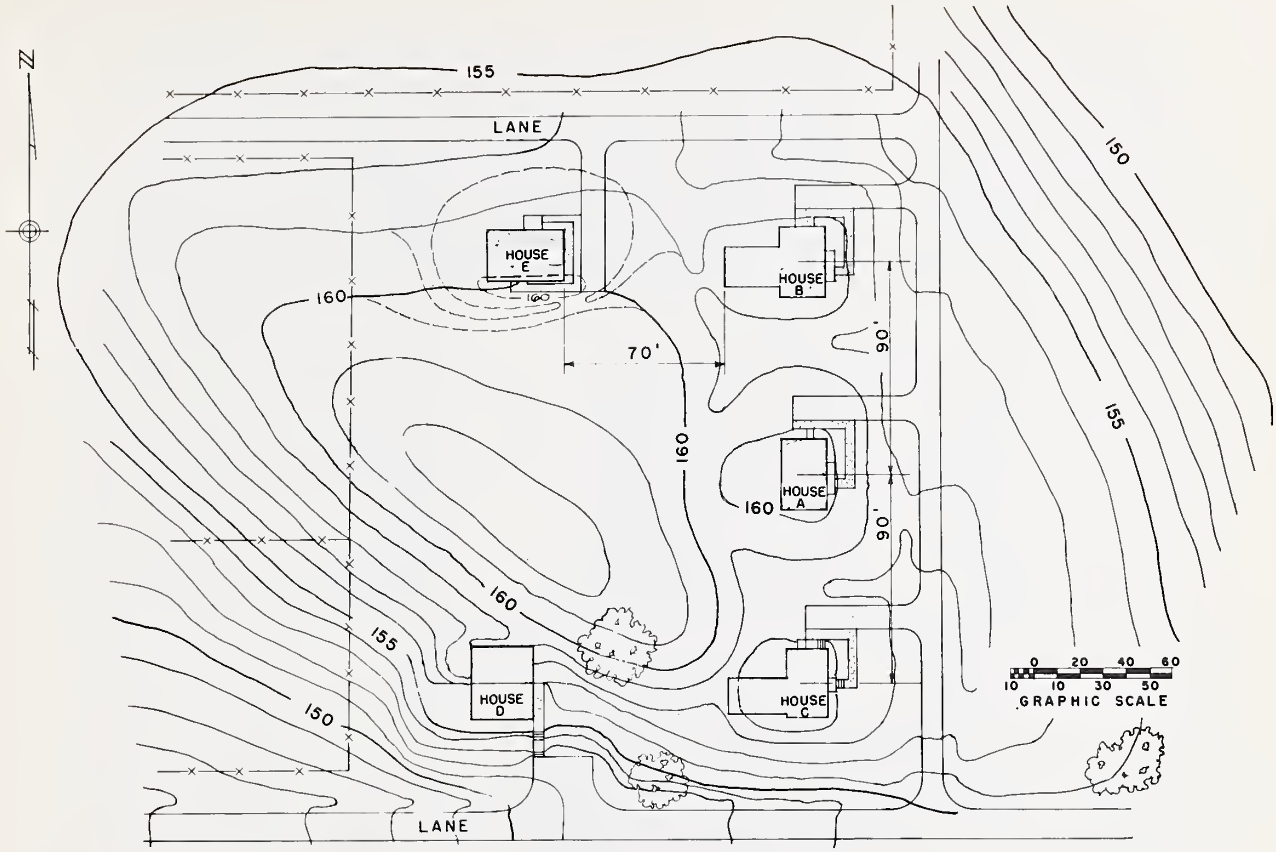


FIGURE 6.--Site plan.

and auxiliary heaters was measured rather than fuel consumption. Coefficient of performance measurements on the heat pump were also made. House B was vacant from April 1955 to February 1956, but was maintained at normal temperatures during the heating season.

A small weather station was maintained about midway between Houses D and E for the entire period of the tests. During later studies air temperature was measured by a thermocouple mounted underneath a sheet metal shade above the gable end of House E. A three-cup rotating anemometer gave totalized readings of wind velocity for daily periods usually terminating at noon. Later the anemometer was connected to a recorder.

Weather records from the Weather Bureau Friendship Station in Baltimore, Md., and the Airport Station in Washington, D. C., were also used. Radiation measurements were taken from special records furnished by the Silver Hill Observatory staff in Washington, D. C.

Thermocouples were used for all temperature measurements in Houses A, B, C, and D. They were mounted on the walls about 60" above the floor and partly shielded from radiation and mechanical damage. All junctions in each house were connected in parallel to give an average reading on one recording point. Insofar as possible, locations were selected on interior walls and partitions to give representative temperatures for the entire house. In Houses B, C, and D four couples each were used, one for each bedroom, one for the living area, and one for the kitchen and dining area. Only two junctions were used in House A since it is much smaller than the others and does not have bedrooms separated from the living portion of the house. In House E, inside temperatures were measured by a 6" diameter black globe thermocouple in the center of the house at a height of about 7 feet, and by an air-type thermocouple in the return air stream of the air-conditioning unit. Temperatures in all the houses were recorded by a 16-point potentiometer printing one point every 30 seconds. The recorder was

Table 1.--Construction in basic units of experimental farmhouses.

Item	House[1]				
	A	B	C	D	E
Foundation	Reinforced concrete beam on concrete posts set 2' below grade.	Concrete block on concrete footings 2' below grade.	Brick piers on concrete footings set 2' below & extending 18" above grade with asbestos cement board curtain wall.	Concrete block on concrete footings set 2' below grade.	Reinforced concrete 6" thick set 10" below grade.
Floors	Concrete slab on earth underlaid with 55# roll roofing & covered with linoleum, rubber, and plastic tile.	Concrete slab on 6" gravel bed underlaid with 55# roll roofing and covered with asphalt and plastic tile.	Double wood floors over crawl space. Ground in crawl space covered with vapor barrier of 55# roll roofing.	Concrete slab on 6" gravel fill with 55# roll roofing beneath. Covered with asphalt tile & linoleum. (Bedroom and bath exposed concrete).	Concrete slab laid over 12 beds alternate gravel and earth. One-half slab underlaid with vapor barrier.
Exterior walls	Wood frame. Studs 24" o.c. covered outside 4x8 sheets asbestos cement board. No sheathing but walls braced by corner let-ins.	8" lightweight block painted outside with cement paint.	Wood frame. Studs 16" o.c. with diagonal sheathing spaced 2' apart and covered on outside with vertical T&G siding.	SCR brick 6 inches thick.	Wood frame. Studs 24" o.c. covered outside with corrugated aluminum on spaced nailing strips.
Windows	Frameless - (studs used as jambs). Fixed glass with barn sash hinged at top to provide ventilation.	Wood, double hung.	Wood, double hung.	Wood combination fixed glass and awning type sash. Glazed with insulating glass.	Fixed sash set between studs. Operating sash - horizontal sliding aluminum.
Interior finish	Dry wall (gypsum board with taped joints).	Gypsum plaster on walls. Gypsum lath and plaster on partitions and ceiling.	Gypsum lath and plaster.	Kitchen gypsum board. Bath - exterior grade plywood. Balance of walls exposed brick.	Utility-asbestos cement board. Bath - hard board. Balance plywood.

See footnotes at end of table.

Table 1.--Construction in basic units of experimental farmhouses--Continued

Item	House[1]				
	A	B	C	D	E
Roof	Light-weight wood trusses, 1" wood sheathing covered with 15# felt, asphalt shingles.	Light-weight wood trusses, 1" wood sheathing covered with 15# felt, asphalt shingles.	Light-weight wood trusses, 1" wood sheathing covered with 15# felt and asphalt shingles.	2" T & G plank on rafters spaced 24" o.c. exposed on inside and covered with 2" insulation & corr. alum. outside.	2" insulated roof plank on rafters spaced 4' o.c. exposed on inside and covered outside with corrugated aluminum.
Insulation	Two inches in walls and ceiling with vapor barrier backing.	Two inches in roof. Cores of block on north and west walls filled with expanded mica.	Two inches in walls and ceiling with vapor barrier backing.	Two inches on roof.	Walls-aluminum foil reflective insulation. Roof 2" insulation plank.
Heating equipment	Circulator heater vaporizing pot, No. 1 fuel oil, without fan.	Two circulator heaters to October 1956 then forced warm air oil-fired central system. Supply ducts in attic. Ceiling outlets, hallway returns.	Two circulator heaters to December 1955, then forced warm air oil-fired central system. Supply ducts in attic. Ceiling outlets, returns in crawl space.	Forced warm air oil-fired system with perimeter supply ducts of heavy paper cast into concrete floor.	Heat pump, air-to-air type. Heat distributed through overhead metal ducts and outlets. Hallway returns.
Floor area sq. ft.	[2] 567	[2] 940	[2] 900	[2] 833	[2] 731
Window area sq. ft.	115	143	174	250	170
Percent of floor area	20	15	19	30	23

[1] Detailed plans and working drawings available through the Agricultural Extension Service in some States for houses A, B, C, D, and E, under Plan Nos. 7061, 7062, 7079, 7128, and 7130, respectively.
[2] Floor area includes partitions but not exterior walls.

usually controlled by a time clock which permitted all 16 temperatures to be measured twice at the beginning of every 2-hour period.

Fuel consumption was measured by the use of indicating gages mounted on the end of the fuel tanks.

Estimates of burner efficiency for heat conversion in the heating systems were not too satisfactory. Therefore, heat input estimates for Houses A, B, C, and D are sometimes given in terms of gallons of fuel oil or kerosene, and an average efficiency of 70 percent was used in making certain calculations and comparisons. The circulator in House A had no thermostat so that temperatures may have been higher than normal on some winter days when the tenants were absent.

Additional measurements were taken during the 1956-57 heating season on fuel consumed by the burners in Houses B, C, and D. Operational recorders were connected in the burner motor circuits to record the "on" time. Such measurements were correlated with linear measurements of fuel depth by use of indicating gages.

RESULTS OF STUDIES

Houses A, B, C, and D, December 1955-January 1957

The relationships between fuel consumption and inside-outside air temperature differences at various levels of wind and sun are plotted for Houses A, B, C, and D in Figure 7, for the period December 1955 to February 1, 1957. Table 2 gives the fuel rates taken from Figure 7 for a 40° inside-outside temperature difference.

Table 2.--Fuel consumption rates for various wind-sun classifications at 40° inside-outside air temperature differences, for Houses A, B, C, and D during period December 1955-January 1957.

Wind-sun classification	High wind high sun	Low wind high sun	Low wind low sun	High wind low sun	Average
House	Fuel in gallons per hour				
A	0.154	0.142	0.135	0.155	0.146
B	.257	.256	.236	.268	.254
C	.232	.237	.230	.230	.232
D	.217	.200	.202	.230	.212

Linear regressions for low wind velocities (below 5 miles per hour average) are shown in the two left-hand sections of each chart (Figure 7) and for high velocities (5 miles per hour and above) in the two right-hand sections. Those for high sun values (above 8.99 langleys per hour) are shown in the two top sections and for low values (below 8.99 langleys) in the bottom sections. During the high sun-high wind periods it seems reasonable to assume that a high heat loss due to wind might be partly or completely offset by high heat gains from solar radiation. The classification of high wind and low sun would normally be expected to give the highest heat losses per degree temperature difference between inside and outside air. Generally, it would not be expected that a simple linear regression of fuel on temperature difference should pass through the zero-zero coordinates because of the electrical heat input to the houses, solar heat gains, and metabolic heat from the occupants; it should go below the zero line on the fuel axis.

For House A, electrical and metabolic heat seemed to have little effect since the regression lines for low sun periods pass through the zero-zero coordinates. High wind resulted in higher fuel consumption with both high and low sun indicating the possibility of high infiltration losses. At low wind the high sun condition required more fuel which is opposite to that ordinarily expected; the variation in dispersion of data might account for this particular reversal of sun effect.

For House B there was no effect of high wind over low wind with high sun but this effect was noticeable with low sun; all regression lines passed below zero on the fuel axis thus indicating some sun, electrical input, and metabolic heat effects.

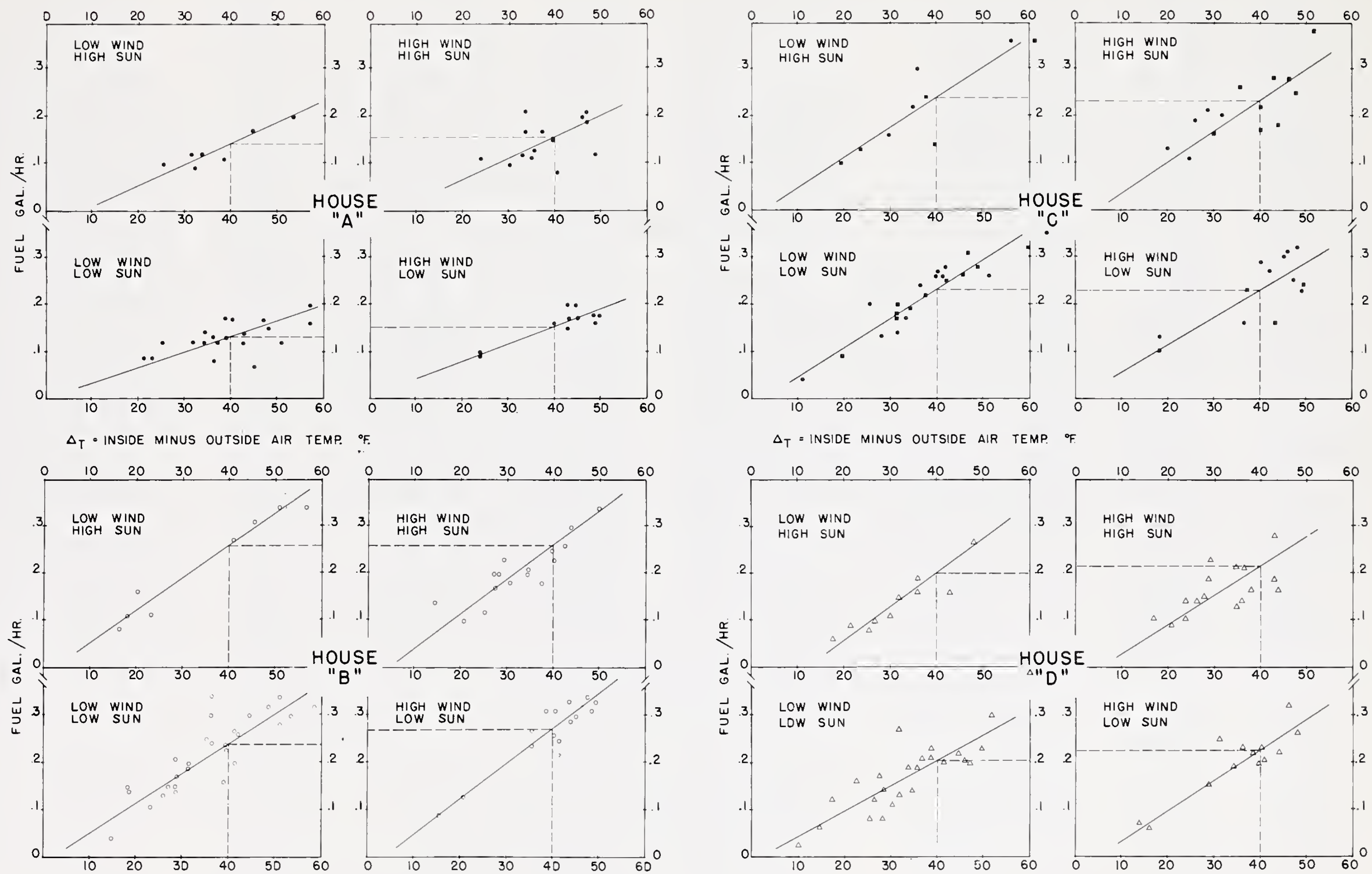


FIGURE 7.--Fuel consumption vs. inside-outside air temperature differences for Houses A, B, C, and D, December 1955-January 1957.

House C showed no effect of high wind over low wind with high sun; a slight effect of high wind with low sun is noted. The maximum difference in fuel rates (40° delta t) for the four wind-sun classifications amounts to only 3 percent. All regression lines passed below zero on the fuel axis indicating the effect of the various supplemental heat sources. The low infiltration loss was apparently the primary factor resulting in the negligible effect of wind.

For House D, as would be expected, the combination of high sun and low wind resulted in generally lower fuel consumption than the other sun-wind conditions. Conversely, high wind and low sun increased fuel consumption. Higher convection losses probably occurred as well as higher infiltration through the wall.

Counteracting influences of high-wind and high-sun are evident since the 40° delta t values for Houses A, B, C, and D are roughly equal to or higher than values in the low-wind, low-sun classifications. With the exception of House C, wind appeared to have a slightly greater effect than solar radiation. Generally, somewhat better overall performance resulted in House D under most wind and sun conditions than in Houses B or C; factors influencing this performance include heat capacity of the masonry wall, greater surface contact with the earth, larger glass area particularly south-facing, use of insulating glass, and window construction affording low infiltration losses.

House E, November 1955-March 1957

An air-to-air heat pump was used for heating House E. Supplemental heating was supplied by means of electrical resistance heaters. Since the heat pump was an experimental unit being studied for various purposes, the performance was not always conducted under normal operating conditions. For this reason the resultant heating supplied to the interior of the house in terms of British thermal unit (B. t. u.) per hour or gallons of fuel per hour is not known precisely for all conditions. This makes it difficult to compare the effects of wind and sun on the aluminum-covered house with the other houses of more conventional construction.

For this initial discussion on the effect of wind and sun on House E, the effective heat input is plotted against the inside-outside temperature difference in Figure 8. This is for a two-season heating period from November 1955 to March 1957. If the effective heat input in kilowatt-hours is converted into fuel oil units, the energy characteristics for House E are quite comparable with those of the other houses.

Classifying the data in the same manner as was done for the other houses, little effect of wind and sunshine on heat input requirements can be noted. Even if solar and metabolic heat input are disregarded, these curves should come close to passing through the zero-zero point since all electrical energy input to the house is accounted for. The solar factor would logically have less influence on heating requirements for this house since it is covered on walls and roof with aluminum and has wide eaves. During most of the winter of 1957 aluminum shields were placed over part of the windows, which would further reduce possible solar effects.

A general observation of the foregoing discussion is that sun and wind effects on fuel requirements may be masked or minimized when weather factors are averaged over time of several days.

Comparison of Houses B, C, D, and E, February-March 1957

Family living habits may influence a comparison between houses to a considerable degree. For example, on calm, sunny days some housewives may open the windows more to "air out" the house; with automatic heating systems more fuel or electricity might be used than on windy, cloudy days. The number of times doors were opened, whether more door openings occurred during the warmer or colder parts of the day, and the amount of ventilation permitted in the bedrooms at night are all variable factors, which would not be comparable for the different families involved. Procedures in using

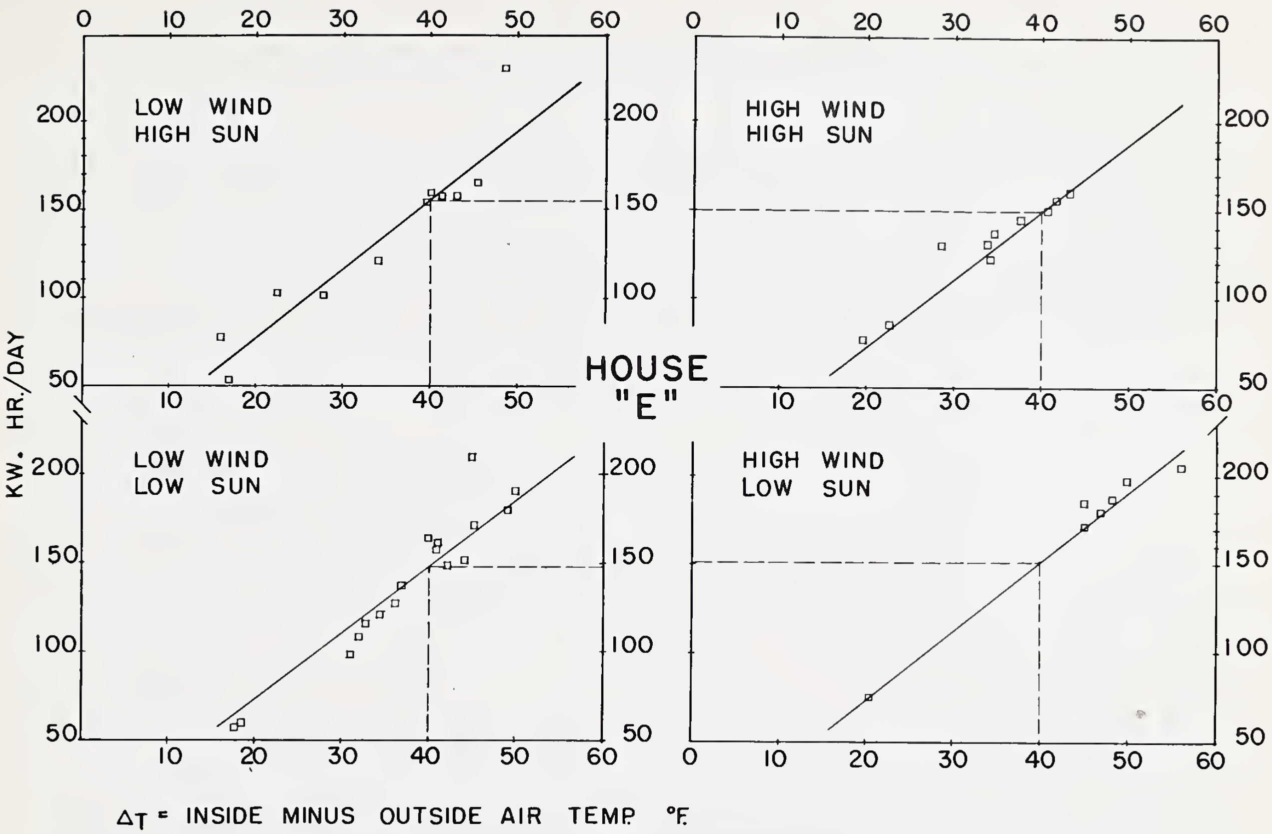


FIGURE 8.--Electricity consumption vs. inside-outside air temperature differences for House E, November 1955-March 1957.

drapes, curtains, and venetian blinds may have had some influence. No detailed records were made on such practices followed by the occupants of these houses. This is one of the practical problems difficult to solve in analyzing "in-use" performance data.

Temperature differences used in House E were based upon inside globe temperatures which may have been several degrees higher than the actual inside air temperatures. Thus, in comparing the houses on an equal delta t basis, the air in the other three houses might have been actually warmer than that in House E. The possibility of using improper coefficient of performance factors in converting heat pump data also presents another complication in comparing House E with the other three houses.

The data for the February-March 1957 period have been summarized in Table 3. This set of data undoubtedly gives a much more accurate picture of wind-sun effects and of fuel consumption than the 1955-57 data, because of changes made in the daily measurement procedures. Windows and doors were probably opened less during these 2 months reducing variability as compared with 1955-57 data which included the fall and spring periods. Snow cover on roofs may also have altered the thermal and fuel responses.

Data given in Table 3 were analyzed statistically. All regression coefficients were highly significant except that for the wind on Houses C and E. This analysis indicates that House D is most affected both by sunshine and wind and House E the least. The analysis shows that the inside-outside air temperature difference (delta t) is the most important factor affecting fuel requirements of all the houses. The relative importance of delta t(X_1), wind (X_2), and sun (X_3) is given for each house as follows:

<u>House B</u> - Delta t accounted for 74 percent of the variation in fuel consumption, wind 1 percent, and sun 9 percent, taken separately. Together the three factors account for 80.68 percent.

Table 3.--Weather and heating requirements, Houses B, C, D, and E, February and March 1957.

Date	Weather[1]			Inside minus outside air °F. (Δt) & fuel, gal./hr.								
	Air temp.	Wind	Sun	House B		House C		House D		House E		
Feb.	°F.	Mph.	Lang./hr.	Δt	Gal./hr.	Δt	Gal./hr.	Δt	Gal./hr.	Δt	Kw./hr.	Gal./hr.
1	35	2.9	1	37	0.24	40	0.26	35	0.15	38	7.1	0.25
2	36	2.0	10	33	.15	40	.24	35	.13	36	6.4	.22
3	38	4.3	4	32	.24	38	.26	32	.17	34	6.5	.23
4	49	6.2	7	23	.15	27	.17	22	.11	24	7.5	.26
5	35	3.2	3	38	.22	39	.28	36	.18	38	7.3	.26
6	32	1.7	3	38	.23	41	.23	38	.22	39	7.5	.26
7	37	1.3	3	34	.21	37	.23	38	.14	33	6.5	.23
8	37	3.3	4	29	.13	36	.26	33	.18	33	6.1	.21
9	39	2.1	3	27	.19	34	.21	31	.09	28	6.3	.22
10	46	8.5	15	27	.21	28	.18	24	.08	24	5.3	.19
11	32	5.4	5	42	.25	43	.29	38	.24	43	7.2	.25
12	27	4.0	16	44	.23	45	.27	42	.20	43	7.7	.27
13	33	1.6	12	39	.24	41	.26	38	.18	36	6.4	.22
14	31	4.8	6	41	.28	43	.29	39	.23	37	7.0	.25
16	36	6.6	8	35	.26	37	.26	34	.18	34	7.0	.25
17	32	8.3	15	39	.29	41	.26	37	.20	38	7.9	.28
18	36	4.4	16	37	.23	38	.25	35	.15	33	6.2	.22
21	31	3.2	17	45	.20	47	.28	40	.20	39	7.4	.26
22	33	1.9	14	41	.20	45	.22	38	.21	41	6.6	.23
23	42	1.7	11	33	.20	36	.20	27	.12	33	6.1	.21
24	42	2.6	15	34	.16	36	.19	28	.11	33	5.5	.19
25	45	1.9	7	28	.14	33	.20	26	.02	29	4.6	.16
26	54	2.9	2	19	.10	22	.11	17	.07	21	3.6	.13
27	54	5.8	10	19	.10	23	.11	17	.06	20	3.6	.13
28	32	7.6	2	43	.26	44	.26	39	.30	41	8.4	.29

See footnote at end of table.

Table 3.--Weather and heating requirements, Houses B, C, D, and E, February and March 1957--Continued

Date	Weather[1]			Inside minus outside air °F. (Δt) & fuel, gal./hr.								
	Air temp.	Wind	Sun	House B		House C		House D		House E		
March	°F.	Mph.	Lang./hr.	Δt	Gal./hr.	Δt	Gal./hr.	Δt	Gal./hr.	Δt	Kw./hr.	Gal./hr.
2	39	5.1	13	34	0.20	41	0.24	31	0.16	34	6.8	0.24
3	31	6.2	20	38	.22	45	.24	38	.17	42	7.1	.25
4	29	3.6	19	43	.20	48	.24	42	.17	45	7.4	.26
5	32	3.1	20	40	.20	46	.23	38	.15	43	8.0	.28
6	37	3.0	9	37	.19	40	.23	34	.18	39	8.0	.28
7	37	4.7	5	36	.19	41	.25	33	.15	39	6.4	.22
8	39	8.2	4	35	.20	38	.25	31	.18	36	6.6	.23
11	39	3.3	16	32	.17	39	.22	32	.05	35	6.1	.21
12	51	5.1	14	21	.15	27	.16	21	.08	22	4.8	.17
13	50	4.7	19	17	.08	26	.15	22	.08	24	4.2	.15
14	53	4.6	20	15	.07	22	.09	19	.06	20	3.7	.13
15	56	3.2	6	14	.07	16	.07	14	.04	19	3.4	.12
16	51	5.1	21	18	.09	23	.13	21	.09	23	3.9	.14
17	49	4.1	19	22	.12	24	.13	20	.06	25	4.6	.16
18	44	3.7	11	26	.12	29	.19	26	.13	30	5.1	.18
19	40	6.9	2	29	.14	36	.22	30	.16	35	6.0	.21
20	41	6.7	5	28	.17	35	.23	30	.16	33	6.0	.21
21	42	6.5	18	26	.15	32	.22	29	.14	31	5.3	.19
22	41	3.0	4	28	.15	33	.22	31	.17	31	5.5	.19
23	45	4.4	23	22	.09	30	.18	26	.04	29	4.3	.15
24	48	3.9	17	19	.09	26	.13	23	.08	26	4.5	.16
25	39	6.4	5	30	.16	34	.23	31	.18	35	6.4	.22
26	42	4.6	14	29	.16	31	.20	29	.13	32	4.6	.16
27	44	5.1	10	25	.12	31	.19	28	.13	30	4.6	.16
28	42	3.3	8	25	.10	32	.20	28	.13	32	4.9	.17
29	43	4.6	19	19	.11	31	.19	27	.13	31	4.8	.17
30	42	7.2	16	28	.13	33	.21	28	.13	31	5.8	.20
31	39	3.7	26	29	.11	34	.17	32	.12	32	5.0	.18
Avg. (53 days)	40.2	4.4	11.2	30.6	.171	35.0	.211	30.4	.139	32.7	5.9	.208

[1] Air temperature measured with a shaded 22-gage copper constantan thermocouple; wind at about 8-feet above ground with a recording 3-cup anemometer; sun by the USWB local station pyrheliometer in langleys per hour for 24 hour days. Langley is 1 gram calorie per square centimeter.

House C - Delta t accounted for 78.0 percent of the variation, wind 0.16 percent, and sun 9 percent, taken separately. Together they explain 85.02 percent of the variation.

House D - Delta t explained 64.19 percent of the variations, wind 2.73 percent, and sun 10.88 percent, taken separately. Together they accounted for 77.60 percent, indicating very little overlapping effects.

House E - Delta t accounted for 71 percent of the variation in fuel consumption, wind 0.32 percent and sun 6.87 percent when each factor is taken separately. Together they account for 75.35 percent.

Wind effects were found to be closely related to delta t. Soil temperature by itself would seem important but it actually added little to the multiple correlation values. These results follow the same general trend as the 1955-57 data.

Figure 9 presents graphically the statistical analysis of daily averages given in Table 3. All regression lines, except the no-sun lines for Houses B and C, fall below the zero fuel point which indicates, as with previous data, that some air temperature difference is caused by sun, electrical energy input, and metabolic heat of the occupants. Adjustments were not made in the analysis for heat added by appliances in Houses B, C, and D. The analysis shows that solar radiation during February-March 1957 had a greater influence than during the 1955-57 period. There are two reasons for this: (1) Solar radiation was 50 percent higher in February-March 1957 and (2) the better method of analysis emphasized the difference in effect. House D, particularly, shows this effect. The insulating glass plus high heat capacity in House D and the aluminum covering of House E cause substantial differences in solar responses of these houses. High heat conduction of brick walls may contribute some to the higher wind coefficient for

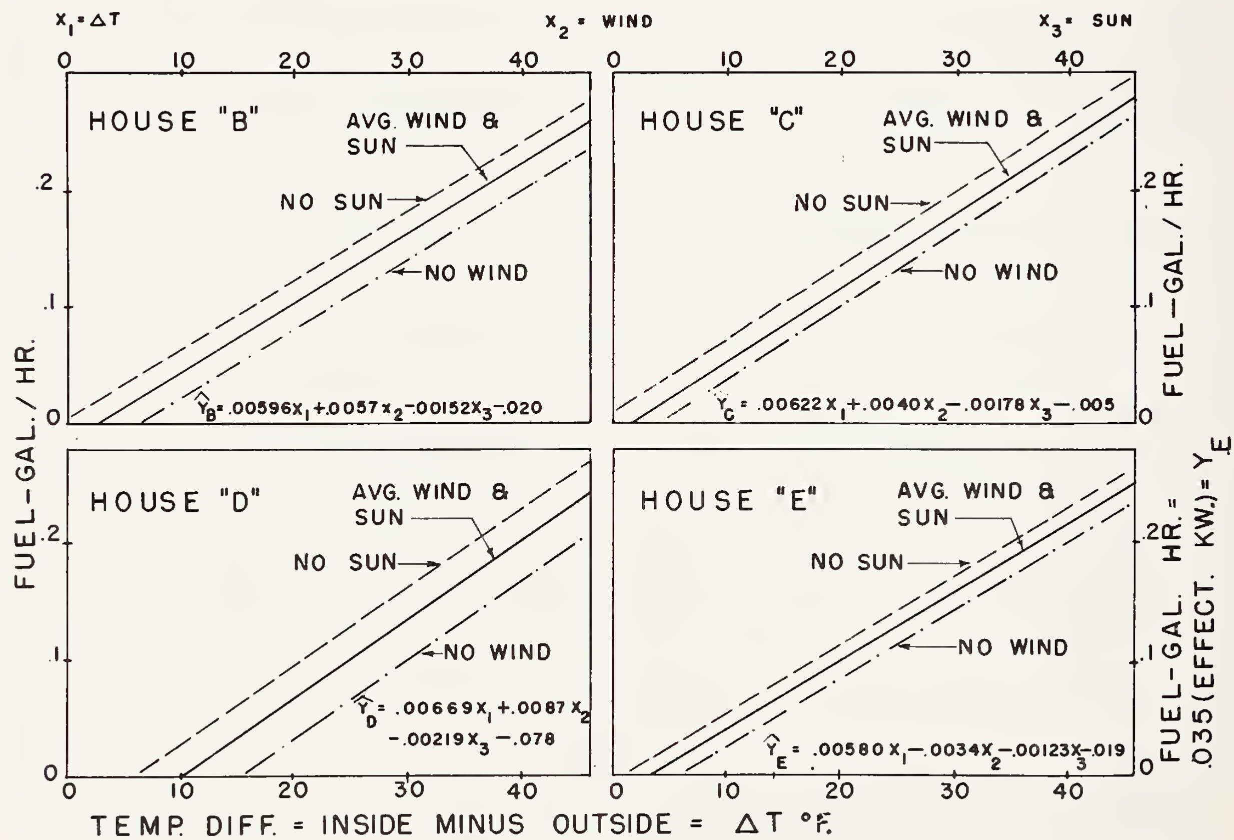


FIGURE 9.--Relationship between fuel consumption and inside-outside air temperature differences with wind and sun effects for Houses B, C, D, and E, February-March 1957.

House D. However, infiltration due to lack of an effective wind barrier in the wall with exposed brick interior surfaces probably was the primary reason for the higher coefficient.

Data were also classified for Houses B, C, and D by periods of days with 80 percent or greater possible sunshine during February and March 1957. Sixteen days were selected from the period summarized in Table 3 to make up the averages plotted in Figures 10 and 11. The use of sunny days only for this comparison removed some of the variability due to cloudiness, rain and other factors.

In Figure 10 sunshine and air temperature, as would be expected, show similar trends, with the peak and cooling portion of the temperature curve lagging behind solar radiation. Wind also shows a somewhat similar trend.

In Figure 11 the fuel consumption per hour was based on the length of time the burner operated each hour and the hourly rate used by the burner. The curves of fuel-delta t ratios were plotted in an attempt to put the houses on a more-or-less comparable basis regardless of the inside temperatures maintained. House D shows the widest variation. It was the only house of the five in which the thermostat setting was lowered every night. Absorption of solar heat by the high-heat capacity walls and trapping of solar heat transmitted through insulating glass helped to maintain a low fuel rate during the first half of the night. The increase in fuel rate in the early morning (between 3 and 4 a.m.) was caused partly by raising the thermostat when the man of the house arose to go to work. A corresponding increase in temperature is not shown since temperatures were recorded only twice at the beginning of each 2-hour period. Thus any short-time temperature variation would not be apparent. A high fuel rate when the family arose and raised the thermostat again was obviously required to bring the temperature of the air and that of the structure up to the daytime level.

The effect of solar heat input in reducing fuel consumption throughout the day and early part of the night can be readily observed. Under the high sun conditions prevailing House D took less fuel than either Houses B or C.

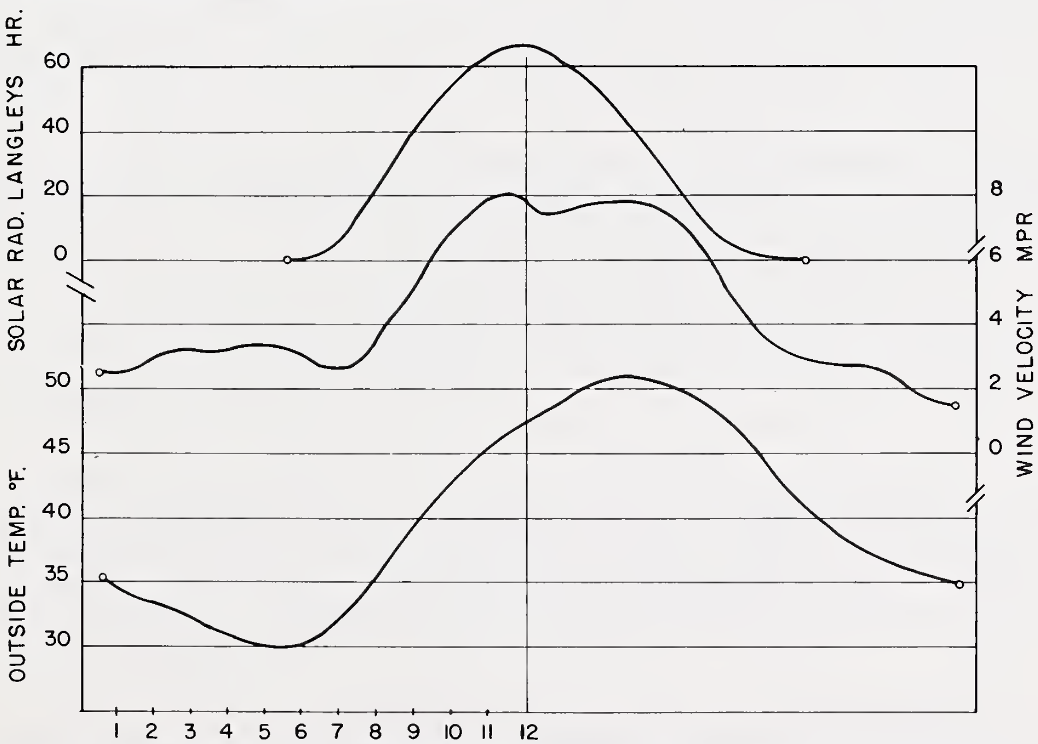


FIGURE 10.--Weather factors for 16 selected days with 80 percent possible sunshine during February and March 1957.

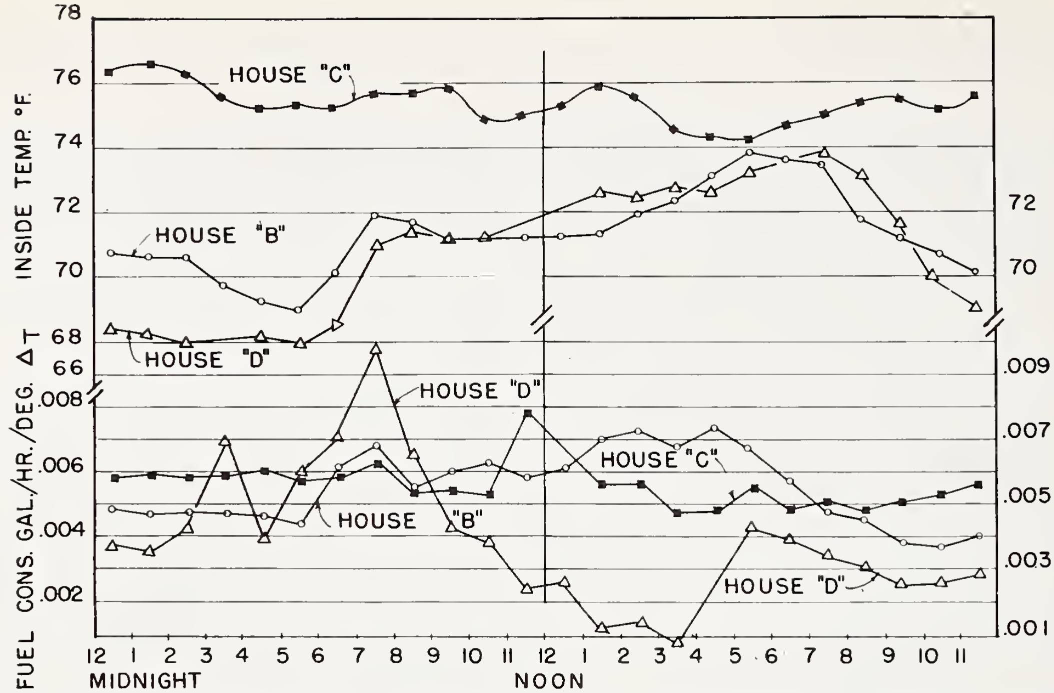


FIGURE 11.--Inside temperatures and fuel--delta t ratio for 16 selected days with 80 percent possible sunshine during February and March 1957.

The temperature curve for House B is somewhat similar to that for House D, indicating the effect, less pronounced, of the heat capacity of walls and floor. The setting of the thermostat was evidently lowered some of the nights during this period and was raised in the early morning.

The temperature and fuel rate for House C were quite uniform throughout the 24 hours, a slight effect of sun being noted during the afternoon hours. The sharp rise in fuel consumption in House C shortly before noon was apparently due to certain family activities and not to wind effect.

While the temperature data obtained were considered adequate for comparing fuel use, they are not necessarily a measure of relative comfort of the houses. No study was made of vertical or horizontal temperature, distribution, nor of radiation effects. A further study to include these factors is planned.

Calculated Heat Losses Versus Consumed Oil Heat Losses

In a further study of the reasons for the reactions to wind and sun obtained for the four houses, it was decided to determine where the greatest heat losses occurred in each house and how calculated losses would compare with the heat from consumed oil and other sources. The 16-day period in February-March 1957 with 80 percent of greater possible sunshine, used in a previous analysis, was selected for this study.

Table 4 gives the calculated heat losses in B.t.u. per hour per degree difference in inside-outside temperatures (delta t) for Houses B, C, D, and E. With certain exceptions "U" values used in computing theoretical heat losses were based on recommendations in the ASHRAE Guide.[2] The "U" value for SCR brick was taken from Technical Notes[3] published by Structural Clay Products Institute. Values for aluminum foil and air spaces bounded by aluminum were taken from a report[4] by the U. S. Bureau of Standards.

[2] Heating Ventilating Air Conditioning Guide, 38th Edition, 1960. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., New York, N. Y.

[3] Technical Notes on Brick and Tile Construction, Vol. 4, No. 2, February 1953. Vol. 10, No. 2, February, 1959. Structural Clay Products Institute, Washington, D. C.

[4] Thermal Resistance of Air Spaces and Fibrous Insulation Bounded by Reflective Surfaces. By H. E. Robinson, L. A. Cosgrove, and F. J. Powell, BMS 151, Nov. 1957. U. S. National Bureau of Standards, Washington, D. C.

Table 4.--Calculated heat losses for Houses B, C, D, and E[1]

House	B.t.u. per hour per degree inside-outside air temperature differences						
	Walls	Glass areas	Doors	Roof and ceiling	Floor	Air change	Total
B	302.3	157.0	33.0	113.0	84.8	20.2	710.3
C	77.0	205.3	26.2	108.0	255.5	21.6	693.6
D	343.5	122.4	21.8	121.0	146.0	27.3	782.0
E	103.9	200.6	21.1	138.3	65.6	22.8	552.3

[1] No corrections made for solar electrical or metabolic heat gains.

Infiltration losses were calculated on the basis of crack, wall, and ceiling leakage, and door openings. The number of door openings daily was estimated for each house depending upon the number of children and family activities. No allowance was made for losses which might have occurred in opening windows as the occupants indicated a minimum of such ventilation in winter. The method used in calculating air change losses can account for a greater variation in total loss than any other component.

Inside temperatures were adjusted to allow for temperature changes above and below the breathing level except for House D which had a perimeter heating system in the floor slab. Attic temperatures in Houses B and C were assumed to be equivalent to outside temperatures because of ventilation through screened rake and cornice openings. Heat loss through the roof was thus disregarded.

The figures in Table 4 indicate that calculated wall losses in Houses B and D were much greater than for any other component. In House C the floor loss was greatest followed closely by the glass area loss. In House E, the glass loss was greatest. As indicated, these losses were calculated by methods ordinarily used by engineers in which corrections are not usually made for electrical appliance input, solar radiation, metabolic heat, and duct losses.

Total calculated losses for actual delta t values in Houses B and D are about 35 and 91 percent higher, respectively, than the consumed oil heat quantities. The calculated loss is about 14 percent lower for House E whereas no difference is indicated for House C. Thus heating estimates, made on the basis of losses calculated in the usual manner, may be considerably in error. The variations which can occur between actual and computed heat losses are wide and it is difficult to apply sound engineering judgment in making allowances for variables when estimating heating requirements to such a close degree required in a study of this type. High-heat capacity apparently has a greater effect than is ordinarily believed thus justifying further evaluation of factors involved in a complete heat balance for each house.

The equation Q = U A x delta t for computing heat transmission losses is valid only when a constant temperature condition exists for the entire period under consideration, the flow of heat is unidirectional, and the flow is unvarying in magnitude. These conditions are seldom obtained outside the laboratory. Steady flow conditions may be approached in actual construction under certain conditions for very thin barriers such as glass or other dense materials. As the thickness and mass of the barrier increase, the thermal resistance and thermal storage capacity of the construction tend to defeat the validity of the steady flow equation.

Complete heat balances including all known sources of heat for the three houses were calculated. Gains from heat supplied by electrical appliances comprised a major source of the supplemental heat. Estimates were made of the amount of hot water used daily and

40 percent of this was considered as wasted. Metabolic heat gains were calculated, using rates published in the ASHRAE Guide, and based on estimates of the number of hours spent by each member of the family in various activities. Heat savings from the use of curtains in Houses B and D were based on data from an English reference,[5] which indicated savings of 27 percent in the use of heavy curtains or drapes and 19 percent for light curtains. Curtains were drawn about 12 hours each night.

Solar gains are ordinarily figured as a summertime cooling load, and data for calculating these gains are available in the Guide[6] and other references. The Guide[6] provides a method of correcting the temperature differentials given for calculating heat gain through sunlit walls, roofs and windows for months and latitudes other than given in the tables. This method was used in estimating the solar heat gains in winter. Corrections were made for shading of walls and windows by eaves and rake overhang, for the difference in number of hours of sunlight available on March 1 as compared with the Guide[6] data for July, and for spreading the solar gain over a 24-hour period.

The resulting calculated gains are shown in Table 5 and the net calculated losses are compared with heat supplied by consumed oil in Table 6. Values of heat from oil consumed have been corrected for heat losses from ducts which amount to 20 and 31 percent of the total heat delivered by the furnaces in Houses B and C, respectively. The supply ducts for these houses run through the ventilated attics and are covered with the equivalent of only one-half inch of glass wool insulation thus resulting in a high heat loss. Similar losses probably occur in a large portion of houses so equipped although better fitting and insulating of ducts would undoubtedly be done if the installation is made at the time the house is built.

An excellent heat balance is indicated for House B and that for House D is reasonably good. The high-heat capacity of the walls of House D undoubtedly has a considerable influence in tending to defeat the validity of the heat equation, $Q = U A \times \text{delta } t$. This factor may account for most of the 15 percent difference in calculated and consumed oil losses, although we cannot say with certainty that estimates of solar heat absorption are correct within a reasonable degree of error. Further study of the influence of these factors needs to be made.

The heat balance for House C is entirely unsatisfactory as was expected. The factor of solar heat gain could be primarily responsible as it may be considerably less than calculated in this study because of the high reflectivity of painted wood siding, low mass of the entire structure, and loss of absorbed solar heat by convection currents in the walls and well-ventilated attics.

A comparison was made of the total heat supplied from all sources (corrected for duct loss) per degree inside-outside temperature difference for the three houses. On the basis of both unit floor area and unit perimeter length, House B had the best performance (lowest total heat used) with C next (12 to 13 percent higher) and D last (16 to 18 percent higher). This comparison of the overall performance of the structures is valid only on the assumption that equal furnace efficiencies existed in all houses, that heat gains from solar, electric, and metabolic sources and heat losses from ducts have been accurately estimated, and that equal ventilation occurred through doors and windows.

In all fairness to House D it must be stated that no method has yet been devised for calculating accurately the heat lost from perimeter heating ducts embedded in a concrete slab floor. If this duct loss could be determined, it is possible that House D heat values might equal or be less than those of House C under high-sun conditions. Since the statistical analysis had indicated that sun had the greatest effect on House D, the performance of this house would be lower under low-sun conditions. This would also be true of House B but it is doubtful if fuel consumption would be increased sufficiently to bring it up to the House C level.

---

[5] Thermal Properties of Buildings by N. S. Billington, 1952. Cleaver-Hume Press LTD, London, England.
[6] See footnote 2.

Table 5.--Calculated heat gains for Houses B, C, and D, 16 selected days February-March 1957.

House	Calculated gains				
	Solar	Electrical	Metabolic	Curtains	Total
	B.t.u./hr.	*B.t.u./hr.*	*B.t.u./hr.*	*B.t.u./hr.*	*B.t.u./hr.*
B	5,240	2,980	670	390	9,280
C	5,780	5,510	820	---	12,120
D	5,770	2,410	1,070	540	9,790

Table 6.--Net calculated losses versus net heat supplied by consumed oil corrected for duct loss for Houses B, C, and D, 16 selected days February-March 1957.

House	Calculated			Heat from oil consumed	Duct loss corrections	Net heat used	Diff. between calc. loss and heat from oil consumed
	Gross loss	Gain	Net loss				
	B.t.u./hr.	*B.t.u./hr.*	*B.t.u./hr.*[1]	*B.t.u./hr.*	*B.t.u./hr.*	*B.t.u./hr.*	*Percent*
B	22,070	9,280	12,790	16,400	3,270	13,130	-3.0
C	19,700	12,120	7,570	19,700	6,080	13,620	-44.5
D	24,590	9,790	14,800	12,900	---	12,900	+14.7

[1] Using heat value of 141,965 B.t.u./gal. and furnace efficiency of 70 percent.

SUMMARY

The five expansible-type farmhouses, in which these studies were conducted, were built primarily to house farmworkers. Because the houses were occupied by families of various sizes and habits and the families were not asked to change their regular routine of living, controlled studies were not possible. For this reason it was difficult to compare one house or type of construction with another.

Generally, in the five experimental houses, the 1955-57 data indicated that high wind (5 m.p.h. or greater) tended to offset the effect of high sun (above 8.99 langleys per hour). High wind with low sun generally resulted in increases in fuel consumption as compared with high wind and high sun; the effect was more pronounced with masonry wall construction and less pronounced with conventional wood frame construction having wood or metal siding. With masonry construction the effect of high sun and low wind was more pronounced in reducing fuel consumption than construction of lighter mass.

A statistical analysis of February-March 1957 data showed that both sunshine and wind had the greatest effect on House D (SCR brick and insulating glass) and the least on House E (aluminum covered). The analysis indicated that the inside-outside temperature difference (delta t) was the most important factor affecting fuel requirements of all the houses. In House B (concrete block), delta t accounted for 74 percent of the variation in fuel consumption, wind 1 percent, and sun 9 percent, taken separately; together the three factors accounted for 80.68 percent. In House C (wood frame), delta t accounted for 78 percent of the variation, wind 0.16 percent, and sun 9 percent; taken together they accounted for 85.02 percent of the variation. In House D (SCR brick), delta t accounted for 64.19 percent of the variation, wind 2.73 percent and sun 10.88

percent, taken together they accounted for 77.60 percent. In House E (aluminum covered), delta t accounted for 71 percent of the variation in fuel consumption, wind 0.32 percent, and sun 6.87 percent; taken together the three factors accounted for 75.35 percent.

A comparison of the houses as a whole, including heating systems installed, indicates that House D used the least fuel. This probably resulted from the more efficient delivery of heat from the furnace to the interior of the house.

Heat losses were calculated for the various components of Houses B, C, D, and E by methods ordinarily used by engineers. These methods do not take into account heat from sources other than the furnace or heat losses from ducts. Undoubtedly greater error can occur in the calculation of air change losses than of any other component of the total heat loss. Calculated losses through wall areas were much greater than any other component in Houses B and D. The floor loss was greatest in House C and the glass area loss greatest in House E.

The calculated losses were about 35 and 91 percent higher than heat quantities from consumed oil in Houses B and D, respectively. The loss was 14 percent less in House E whereas there was no difference in House C. Thus heating estimates, made on the basis of losses calculated in the usual manner, may be considerably in error. In Houses B and D, particularly the latter, the effect of mass and high thermal capacity would seem to render invalid the customary formula for figuring heat loss, which is based on steady state conditions with the flow of heat unidirectional and unvarying in magnitude. The variations which can occur between actual and calculated losses are wide and it is difficult to apply sound engineering judgment in making proper allowances for all of the variables when estimating heating requirements.

Since the customary method of comparing actual and computed losses does not take into account gains from solar radiation, electrical appliance heat, and metabolic heat of the occupants, and heat losses from the ducts, efforts were made to calculate heat balances, first for House D and later for Houses B and C. The actual loss for House C, without these gains, was equal to the computed loss but it was desired to determine how much the computed loss would be reduced as a result of any estimating method developed.

An excellent heat balance was indicated for House B and reasonably good for House D. The high-heat capacity of the walls may account for most of the 15 percent difference in calculated and consumed oil losses in House D. The heat balance for House C was entirely unsatisfactory as was expected. High reflectivity of painted wood siding, low mass of the structure, loss of absorbed solar heat by convention currents in the walls, and questionable gains through roofs with ventilated attics undoubtedly contributed to large errors in calculating solar gains.

The total heat supplied from all sources, corrected for duct losses, per degree inside-outside temperature difference was compared for the three houses. On the basis of both unit floor area and unit perimeter length, House B had the best performance (lowest total heat used) with House C next (12 to 13 percent higher) and D last (16 to 18 percent higher). Under low-sun, high-wind conditions the performance of both Houses B and D would tend to be reduced.

Lowering the thermostat setting at night in House D with high thermal capacity in the construction resulted in appreciable differences in furnace operation time per hour over a 24-hour period, due to the heat required for building up wall and floor temperatures to daytime comfort levels. Thus, if a reduction is made in computed loss for such construction (to offset the difference between actual and computed loss), some allowance should be made for this greater short-time demand in sizing the heating plant.